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A Nitrate Signal of Solar Flares in Polar Snow and Ice

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13. ABSTRACT (Maximum 200 words)
The operations described in this report are separated into two sections, one involving the high-resolution sampling, analysis, and interpretation of a firn core from Windless Bight Antarctica and a second section concerned with the acquisition of a 120 meter firn core from the GISP2 site in Central Greenland. Most of the Antarctic work is involved with detailed correlation with records from two drill cores located ~ 10 km apart on the Ross Ice Shelf where snow deposition involves little mixing and highly precise correlations are possible with known solar flare events. In Greenland, a much longer time period of roughly 400 years has been sampled. The core drilling was completed in June 1992 and the cores have been shipped to the National Ice Core Storage Facility in Denver, Colorado. The upper ~ 12 meters of firn core was analyzed on site in Greenland and shows that a high quality ice core record can be obtained.

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MAJOR SOLAR FLARES AND LONG-TERM VARIABILITY IN ANTARCTIC AND GREENLAND ICE CORES

Summary

The operations described in this report are separated into two sections, one involving the high-resolution sampling, analysis, and interpretation of a firn core from Windless Bight Antarctica and a second section concerned with the acquisition of a 120 meter firn core from the GISP2 site in Central Greenland. Most of the Antarctic work is involved with detailed correlation with records from two drill cores located ~ 10 km apart on the Ross Ice Shelf where snow deposition involves little mixing and highly precise correlations are possible with known solar flare events. In Greenland, a much longer time period of roughly 400 years has been sampled. The core drilling was completed in June 1992 and the cores have been shipped to the National Ice Core Storage Facility in Denver, Colorado. The upper ~ 12 meters of firn core was analyzed on site in Greenland and shows that a high quality ice core record can be obtained.

MAJOR SOLAR FLARES AND LONG-TERM VARIABILITY IN ANTARCTIC AND GREENLAND ICE CORES

I. ANTARCTICA

At the recent COSPAR - World Space Congress, held in Washington, D. C. from August 28, 1992 to September 5, 1992 our group presented a paper titled "Major solar flares and Long-term Variability in Antarctic Ice Cores", in the section "Problems in Solar-Activity". The paper which is attached as Appendix A, is scheduled to be published in Advances in Space Research.

The main conclusions of the paper can be summarized as follows. In-situ data acquisition of high resolution nitrate concentrations in Antarctic snow resulting from ionization in the Antarctic atmosphere reveals:

(a) very large solar proton events can be resolved in snow deposited at Windless Bight on the Ross Ice Shelf,

(b) a signal from thermospheric and ionospheric sources is found across the Antarctic ice sheet within the average boundaries of the auroral oval,

(c) long-term periods of high or low solar activity, such as the Maunder Minimum are present in the nitrate record from polar snow and ice.

Clearly, relatively rapid fallout of the ionization products to the surface of the Antarctic ice sheet is a prerequisite for a distinct solar signal. This conclusion is supported by increasing numbers of experimental evidence. The earlier discoveries of polar stratospheric clouds (PSCs) that can act as agents of denitrification in the stratosphere especially at the time of the Antarctic winter vortex when the vortex system tends to act as a chemical and dynamical containment vessel, are now well supported (see references 3 to 6 in Appendix A). However, more information has been added to our knowledge of the fate of ionization products formed at altitudes of auroral activity. This information is being extracted from data from sattelites like the polar orbiting Solar Mesospheric Explorer and Nimbus 7 (see references 7 to 11 in Appendix A).

A second prerequisite in distinguishing a solar signal is the acquisition of high quality data. When working with natural systems the primary aim must be to extract the greatest amount of information contained in the data series that are measured. Snow particulates, once disturbed, constitute a medium that is capable of undergoing rapid changes both physically in terms of crystal size and chemically in terms of its trace impurities. Defining

and reducing the effect of these changes is especially important in our work. This is aided by our high-resolution sampling and on-site chemical analysis.

As shown previously (Dreschhoff and Zeller 1990), large nitrate concentration peaks apparently result from solar proton events (SPEs). These peaks were also found in our new sequence at the corresponding depths, considering that two more years of snow had accumulated on top of the previous surface. The peak representing the August 1972 SPE has been verified by drilling repeatedly and the peaks representing the SPE of 1946 and the white light flare of 1928 has also been sampled repeatedly.

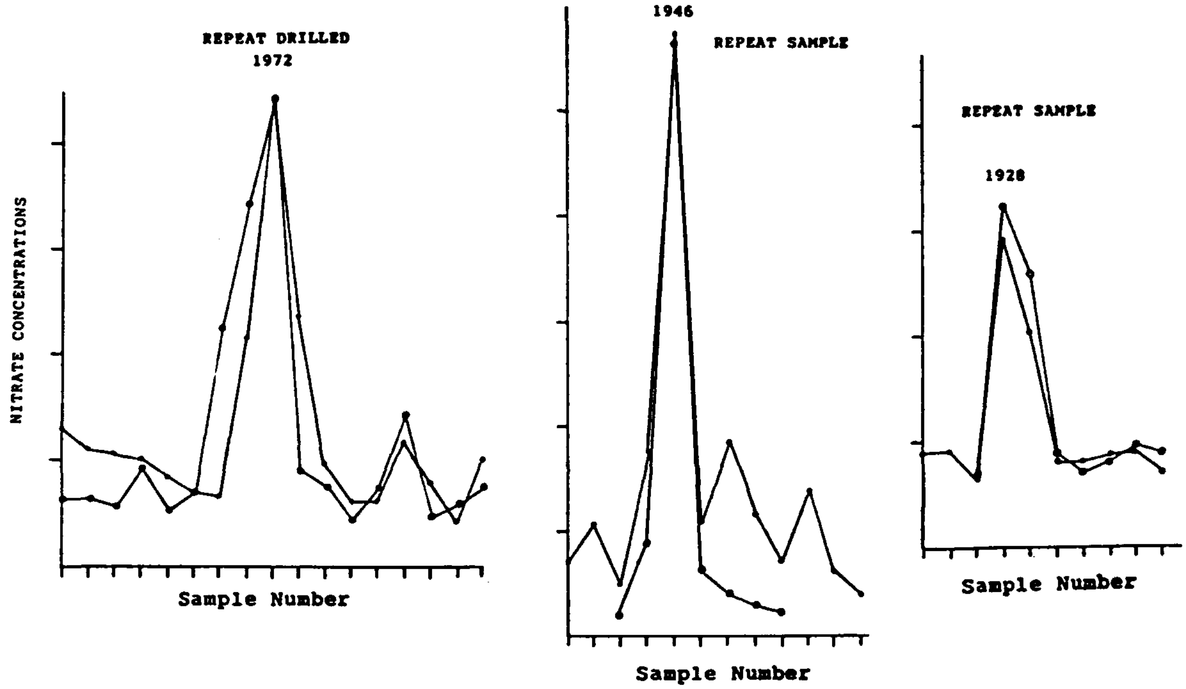


Figure 1. Nitrate concentration profiles of peaks in the Windless Bight snow sequence (see Appendix A, Figure 1). Superimposed are the results of repeat drilling and sampling.

The results are shown in Figure 1. The 1972 peak is >6 standard deviations above the mean and the 1946 and 1928 peaks are ~9 and >4 standard deviations respectively above the mean. From these results it is seen that the 1990/91 sequence is very similar to that found in the 1988/89 sequence from the same area at two drill sites ~ 10 km apart. As pointed out (Dreschhoff and Zeller 1991) the details of the complete sequences do not repeat perfectly and we interpret this as being caused by small meteorological and depositional differences between the two sites. However, new drilling repeated within a radius of a few meters showed that even small, individual peaks could be repeated in great detail. The precision of our measurements is well illustrated in Figure 2, by examining nitrate concentrations and liquid conductivity records from two cores that overlap about 2 m and were drilled less than 1 m apart.

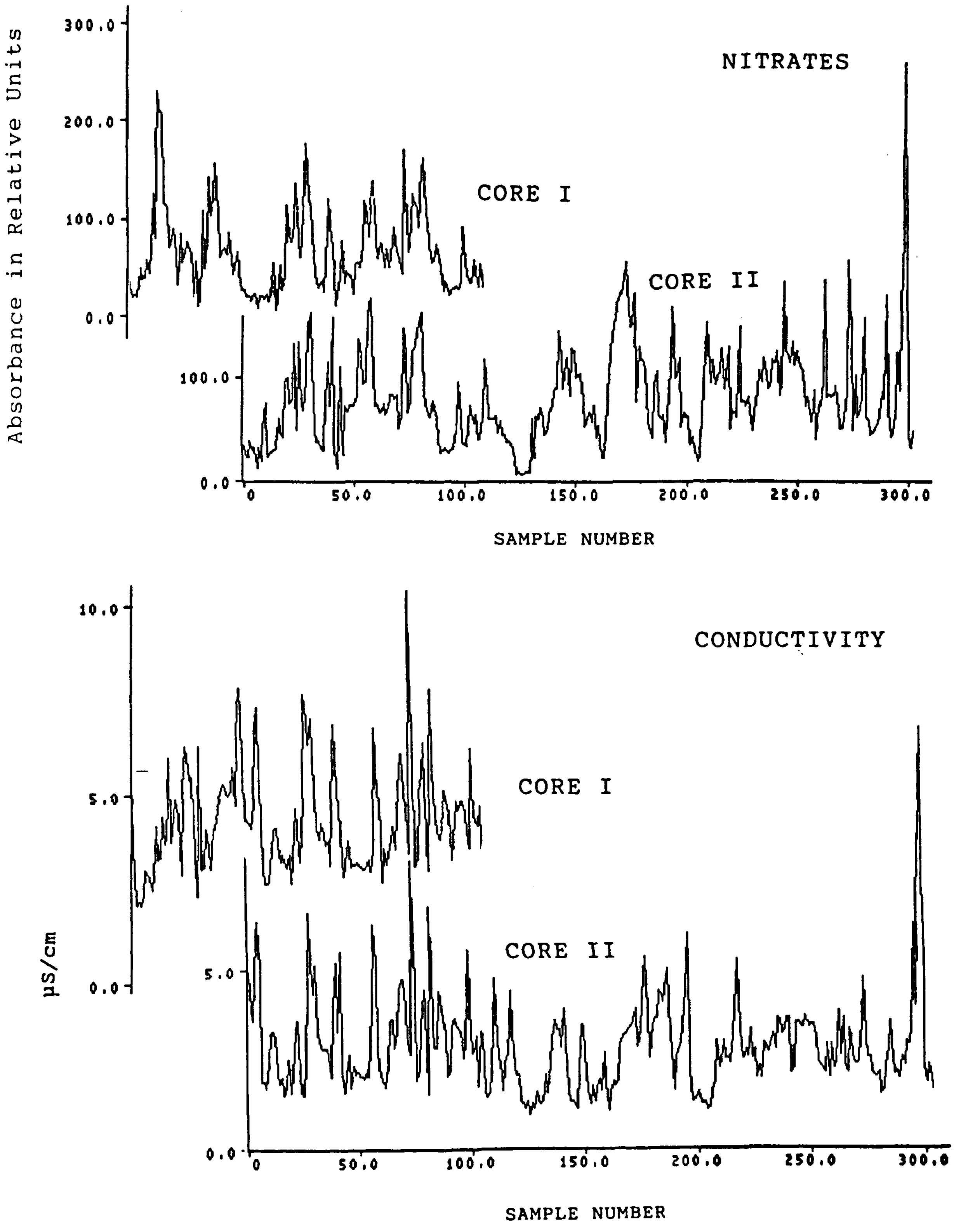


Figure 2. Nitrate concentration and liquid conductivity records from two cores that overlap about two meters and were drilled about half a meter apart.

In addition, the data in this sequence extends to a depth of 29 meters which extends the series by ~ 20 years as compared to the previous series from 1988/89. Near the greatest depth of the firn core, we encountered a dust layer (Dreschhoff and Zeller, 1991), in association with a highly significant peak in nitrate concentration, e.g. 16 standard deviations above the mean, (Figure 3). Superimposed on the graph is the large conductivity peak closely associated with nitrate deposition. Both the chemical species that represent nitrate, and conductivity, which is thought to come from stratospheric sulfates in large part (Legrand 1987; Delmas et al., 1982), could have been transported from the stratosphere to the surface.

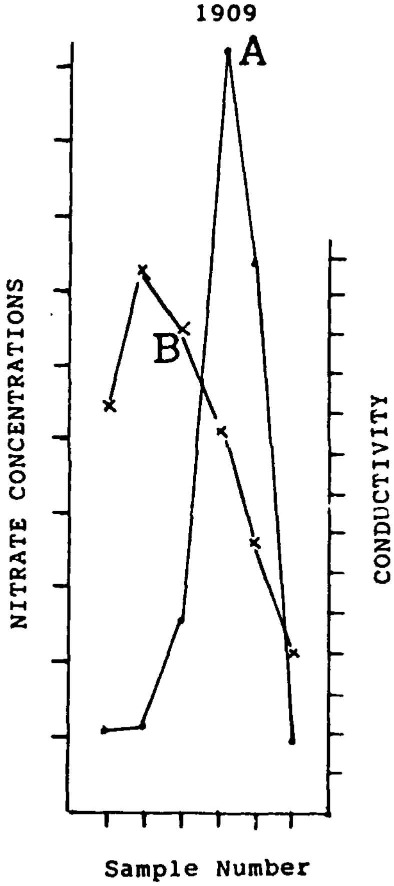
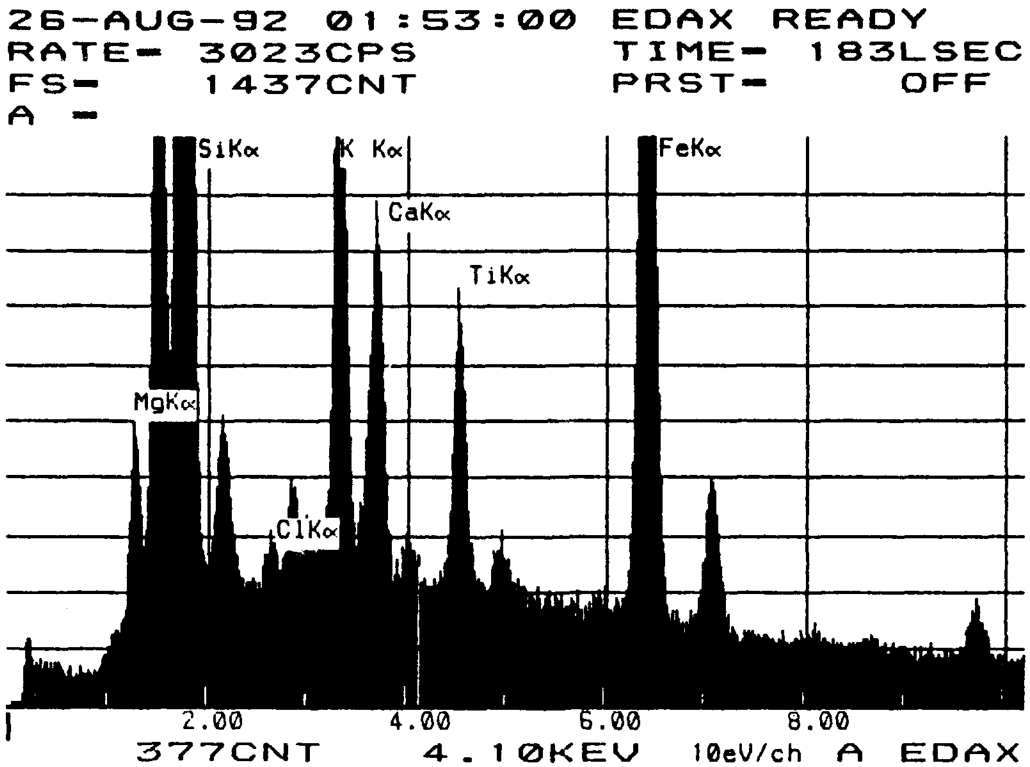


Figure 3. The large nitrate concentration peak (indicated by dots) occurs in snow deposited before the peak maximum of conductivity (indicated by x's). These peaks are associated with a dust layer. Two samples of the dust layer are indicated by A and B and are described in Figures 4 and 5.

The snow containing this nitrate peak fell most probably near the end of 1909. Tentatively we suggest that the peak may result from an SPE. The dust grains in two samples were analyzed at our institution by using a scanning electron microscope (SEM) which can also provide simultaneous chemical analysis. Sample A, as indicated in Figure 3, constituted the center of the dust layer

A



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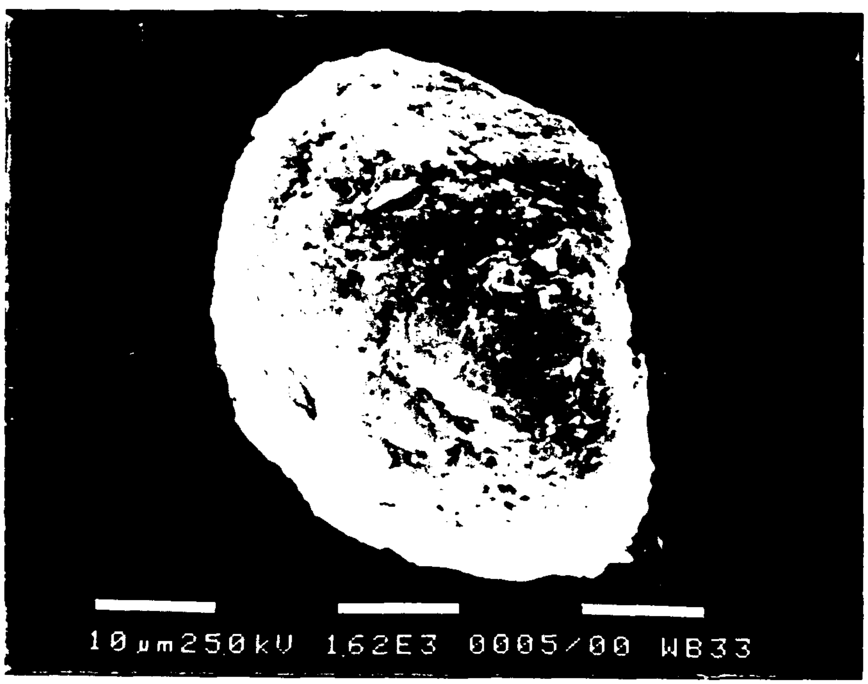
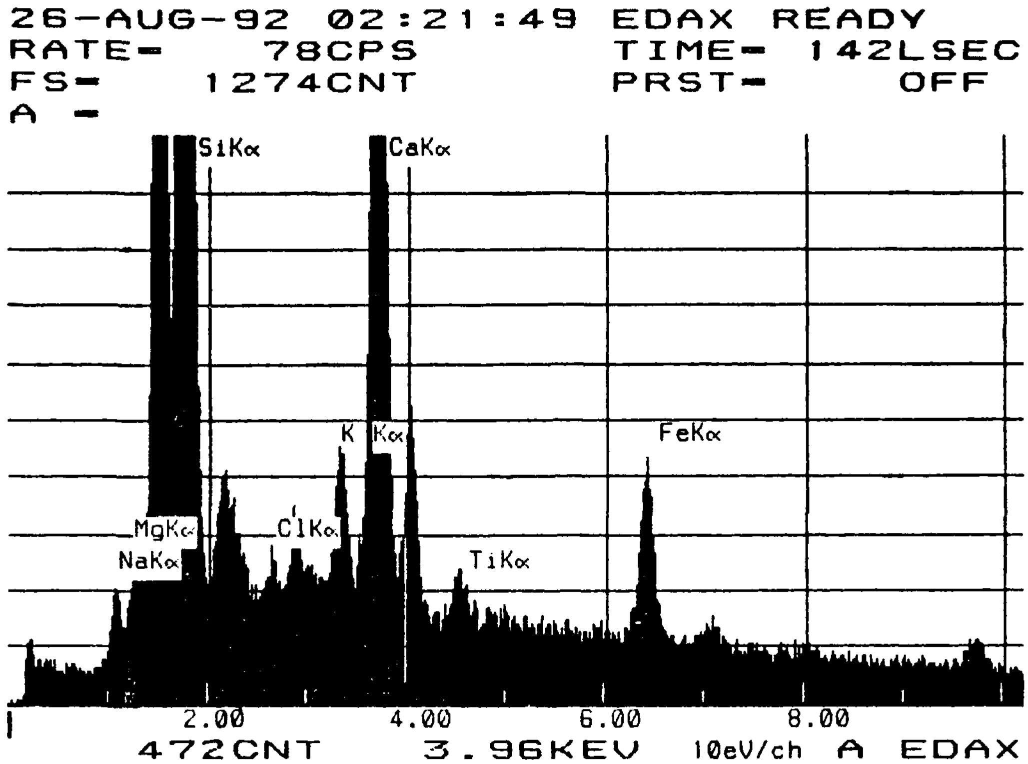


Figure 4. Sample A of the dust layer shows strong rounding probably derived from wind-blown surface dust. The chemical composition of this dust grain is shown in the graph.



B

B

Figure 5. Sample B of the dust layer shows angularly fragmental material probably from the crater of Mt. Erebus. The chemical composition is shown in the graph. Note differences in chemical composition between A and B.

whereas Sample B constituted the adjacent part of the dust layer, much less distinctive visibly. Samples A and B, show some differences in levels of chemical composition (Figures 4 and 5). The SEM photomicrographs also show distinctive differences in the angularity and sharpness of the crystaline grains. Further studies are being conducted at the present time to gain more understanding of the potential source of the dust grains.

Preliminary dating of the 29 m firn sequence has been accomplished, making use of the simultanious conductivity measurements because conductivity is thought to display a seasonable variation (summer/winter). From the discussion above it is clear that this is not strictly the case and must be taken into account. Our 29 m firn core that was hand drilled and analyzed in-situ in Windless Bight begins with snow deposited during solar cycle 14 and ends at the snow surface near the maximum of solar cycle 22. In a sequence of this type, the concentration contained in the snow, as measured, is strongly dependant on the amount of snow that fell over any particular year.

In order to get an estimate of the flux of nitrate to the surface, we date the sequence year by year and determine the average concentration through the year. We then multiply the yearly average concentration by the the total snow accumulation in cm. The result of this flux calculation (in relative units) is shown in Figure 6(a), where the years of solar cycle minima are indicated at the bottom of the graph from solar cycle 14 to 22. The individual solar cycles are even more clearly visible in Figure 6(b) where the flux values have been subjected to a 3 point moving average and no other manipulation has been applied to these data.

We are in the process however, of reducing the pure snowfall effect by analyzing conductivity in terms of its components of contributing negative ions such as nitrate, sulfate, and chloride since the chloride and part of the sulfate are thought to be of marine origin. Once we have this information available, we will be able to delineate more clearly the stratospheric and upper atmospheric signal and improve still further on the nitrate flux variation as representinmg the variability in solar activity for solar cycles 22 to 14.

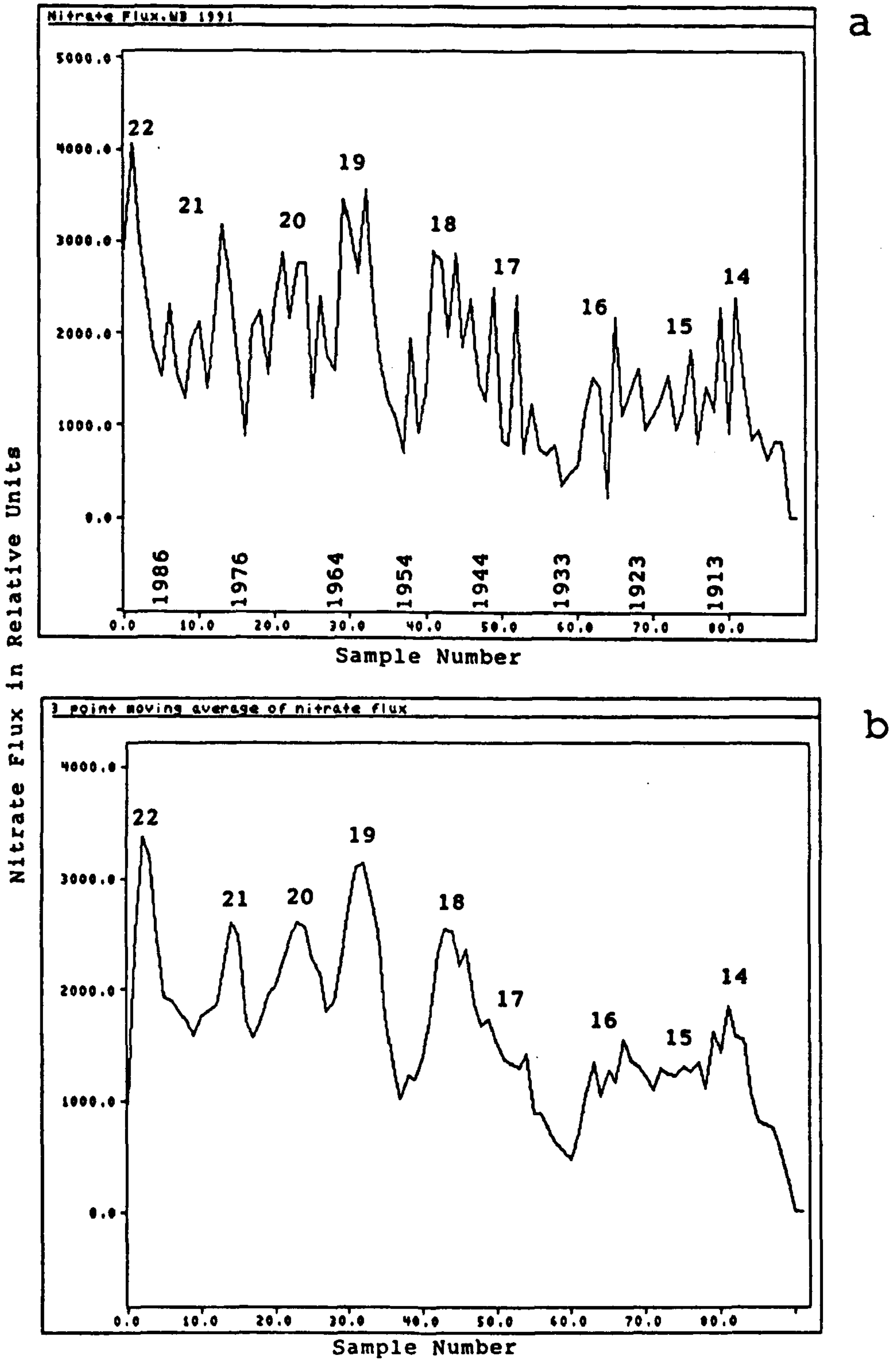


Figure 6. Nitrate flux in the raw data (a) and in three year moving averages (b). The years of solar cycle minima are indicated in (a) and solar cycle numbers are shown in both graphs.

II. GREENLAND

Greenland Field Operation, Summer 1992

From May 27, 1992 until June 26, 1992 we conducted field operations at the Summit drill site, GISP2 (Greenland Ice Sheet Project 2) on the high ice plateau in central East Greenland (Figure 7). At this locality we obtained a 4 inch diameter ice (firn) core which was drilled for us by PICO (Polar Ice Coring Office) from 3 to 9 June, with a mechanical core drill to a depth of 120 meters (Figure 8). During our stay at the GISP2 site, we encountered unusually cold and windy weather conditions. Temperatures frequently fell to -20 F and winds exceeded 40 knots during much of our stay. Visibilities occasionally dropped below 100 ft and usually did not exceed 2 miles in blowing snow. In order to eliminate possible contamination of the core, we remained at the drill site and personally packaged the core segments in insulated boxes. After completion of drilling the 120 meter ice core, we transferred the insulated boxes to the science trench at the GISP2 laboratory and while we were on site, we assisted the staff with continuous measurement of electrical conductivity of the entire core, with the exception of the uppermost 6 meters. The compaction of the snow closest to the surface is not suitable for solid electrical conductivity measurements on that part of the core.

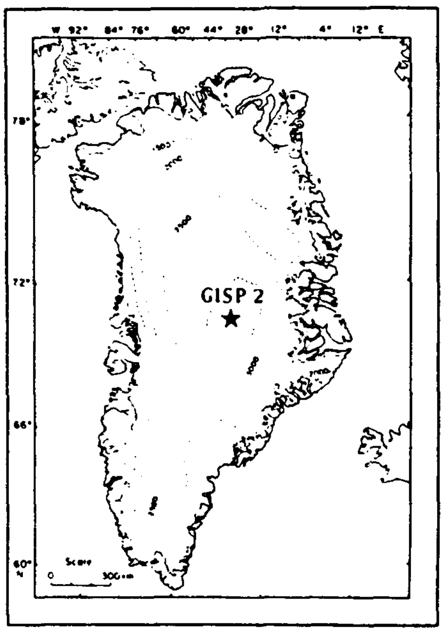


Figure 7. Map of Greenland showing location of GISP2.

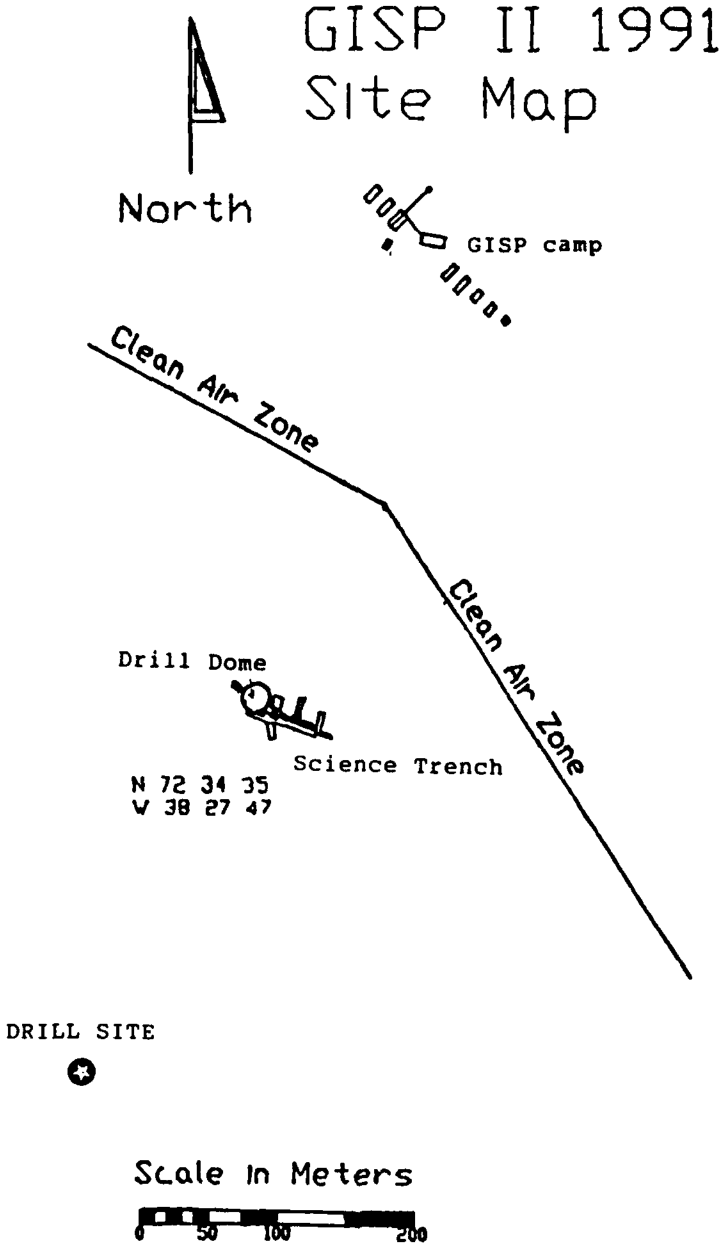


Figure 8. The drill site for the mechanically drilled core is indicated by a star.

While waiting for transportation back to Sondrestrom, we made nitrate determinations using our UV absorption technique on each 1.5 cm of the topmost 12 meters of the 4 inch core. We also drilled a 2.7 meter firn core by hand, 7 km outside and southeast of the main base at GISP2 to provide detailed stratigraphic information about the snow sequence at the Summit Site. This aids in linking the 120 m drill core with the snow sequence deposited during the past ~ 3 years. Drilling this short core proved to be the most hazardous operation that we conducted because we completed drilling and sampling only minutes before a major storm blew into the area without warning and shut down all operations for two days.

On June 26, 1992 we prepared the insulated core boxes for transport to the Air Base at Sondrestrom and accompanied them on the C-130 flight from GISP2 to Sondrestrom where we placed them in refrigerated storage at the Air Base. They have since been transported to the U.S. Polar Ice Core Repository in Denver where we plan to begin analytical work in early 1993, after the newly erected ice core facility is ready to accept visiting scientists.

Hand Drilled Core

We collected pit samples and a hand drilled (3" diameter) core that was sampled immediately as the individual core segments were retrieved from the drill hole, and analyzed about 12 hours later. We considered these samples an important addition that could be substituted for the top portion of our deep, 120 m, mechanically drilled core where mechanical stress can cause crumbling of the upper part of the core. The highest peak in the series is found between about sample 80 and sample 100 (Fig. 9).

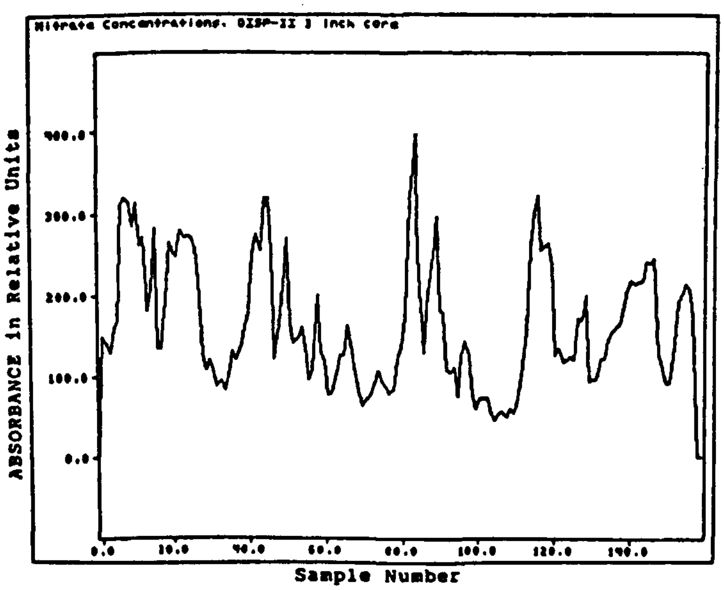


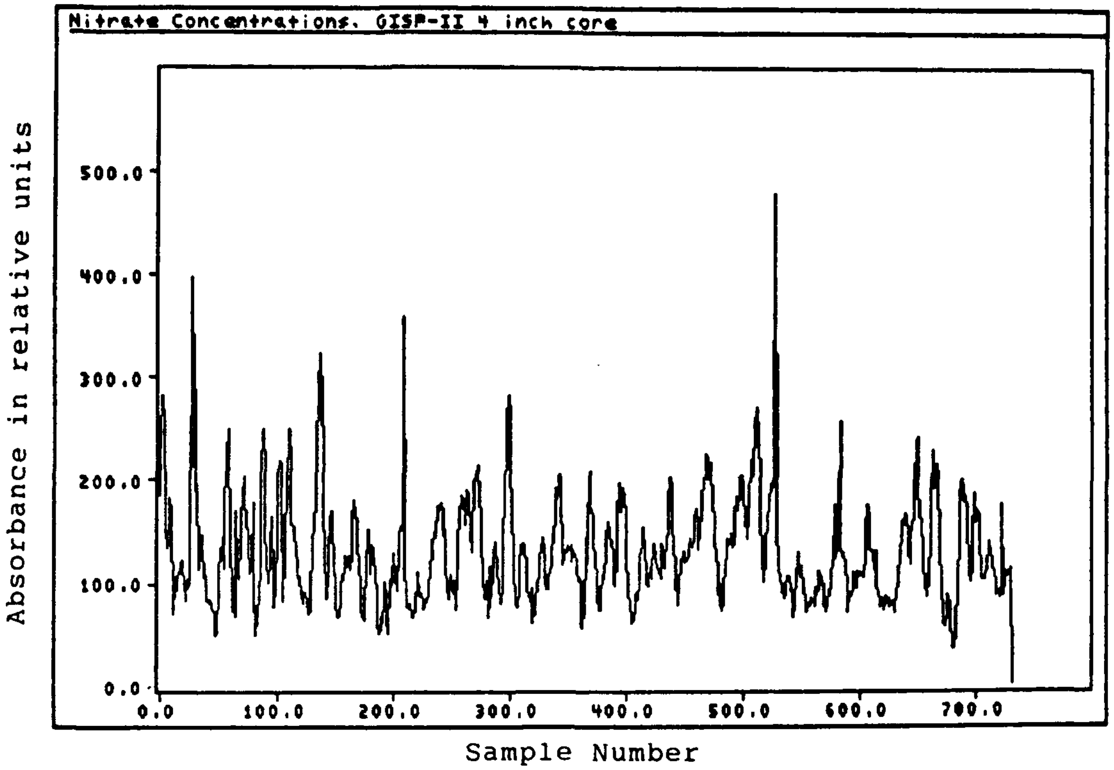
Figure 9. Nitrate concentrations of the hand drilled core from the surface to a depth of 2.7 meters.

At this snow depth, we expect to find the period December 1989 to June 1989 using the depth vs time scale from the GISP2 handbook. The snow is found to contain sharply increasing levels of nitrate what we tentatively interpret as resulting from atmospheric variation caused by a number of large SPEs during that period (Shea and Smart, in press). Unfortunately, at that period, neither Greenland or Antarctica are directly under the influence of the dynamic polar vortex which is a phenomenon of the winter polar atmosphere. Furthermore, from our observations it is clear that the surface at the GISP2 site undergoes strong reworking, at least during a part of the summer. Very clearly defined peaks like those observed in the Windless Bight snow sequence can not be maintained with this degree of mixing of the surface snow. We expect to work closely with some of the scientists that we met at the GISP2 site, who are in posession of snow surface data for the past several years. This may allow us to interpret our data with more confidence.

Mechanically Drilled Core

The upper ~12 meters of the core, (contained in 12 core tubes each containing about 1 meter of 4 inch diameter core) were sampled and analyzed after completion of drilling. The results of both nitrate concentrations and conductivity, are shown in Figure 10. If the dating of the upper ~ 12 meters is based on acidity increases from volcanic eruptions, the largest nitrate peak in the sequence occurs at sample # 529 which corresponds to the year 1977 or possibly 1976 (Zielinski, 1992). This implies that the 1972 period should be encountered very near the break between core tube 12 and the top portion of core tube 13, now at the ice core storage facility. The final dating of the sequence can only be completed after the entire core has been analyzed.

One of the major advantages of our stay at GISP2 was the opportunity to make a direct comparison between our liquid conductivity method and the electrical conductivity method (ECM) that makes solid conductivity measurements of the ice core surface after it has been cleaned and flattened (Figure 11). The year 1977 has been identified by a volcanic eruption and by a major dust storm that occurred in the southwest of the United States (Zielinski, 1992). Differences between the two data sets are not large but when individual peaks are compared between the data sets we find that those measured by the liquid conductivity system seem to be somewhat better developed than those from solid conductivity measurements. We believe that the sharper peak definition in the liquid conductivity measurements occurs because there is ample time for the liquid conductivity to reach equilibrium for each reading whereas the ECM electrodes are dragged at a constant speed over the core surface and large changes in conductivity may not attain equilibrium before the next zone is reached.



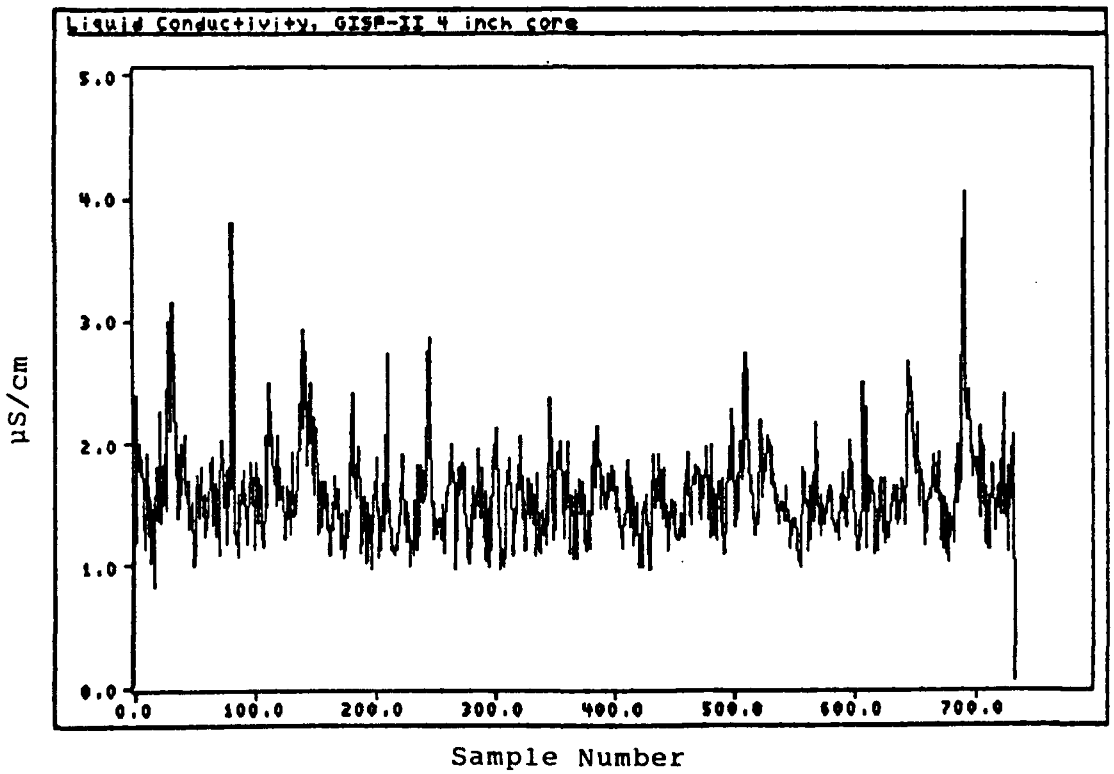


Figure 10. Nitrate concentrations and liquid conductivity of the upper part (about 12 meters) of the mechanically drilled core.

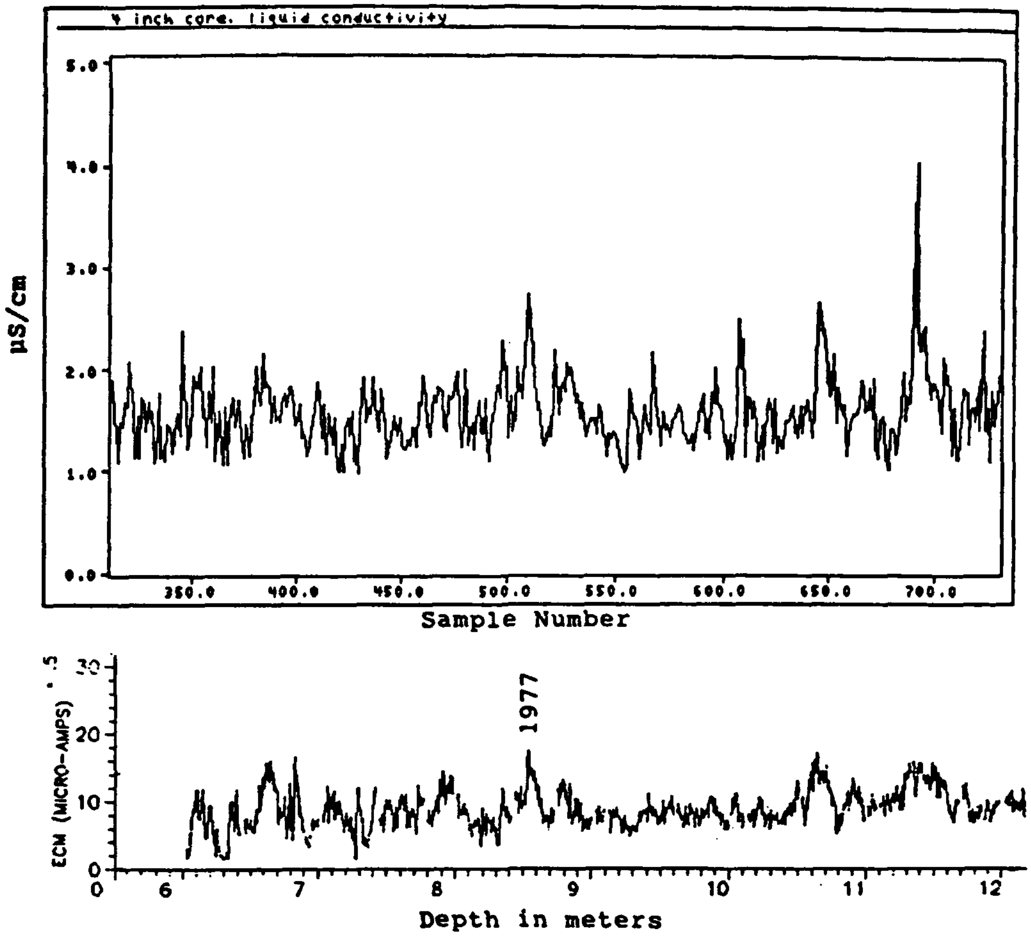


Figure 11. Comparison between liquid electrical conductivity of 1.5 cm samples collected from the core and electrical conductivity measured on the solid core.

At the drill site we were able to obtain a paper print-out of the continuous ECM data for the 4" core from a depth of ~ 6 meters to ~ 50 meters. The complete data set on disk will be sent to us by the University of Nevada. These data have been made available to a number of investigators, and will be of great assistance to us in dating the complete 120 m core.

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Zielinski, G., Personal Communication, 1992.

Interactions and Activities

1. We established close contact with Dr. Paul Mayewski, Director and Chief Scientist, GISP2 Science Management Office, University of New Hampshire and with Dr. M. Legrand of the Laboratoire de Glaciologie, Grenoble, France, during our stay at the GISP2 site, June 1992. We anticipate future cooperative research with these individuals.

2. In a test comparing the analytical results on specific snow samples from from ice cores using our UV absorption technique and ion chromatography from P. Mayewski's laboratory, we are pleased to report a high degree of agreement of all of the results.

3. We cooperated with the University of Nevada, Reno, at the GISP2 site, by making our 120m core available for measurement of electrical conductivity (ECM).

4. The ECM data are available to us for dating the entire core, and will be used by G. Zeilinski to determine specific acidity levels along the core which are related to specific known volcanic eruptions in the past.

5. As a result of discussions at the recent COSPAR meeting we are planning a cooperative paper within the next six months with M. A. Shea and D. F. Smart.

6. Dr. C. H. Jackman of NASA Goddard, Greenbelt, Maryland, visited the University of Kansas, Oct. 5 - 6, 1992. In addition to his lecture for the Physics Department, we conducted a half-day discussion with him and including Dreschhoff, Zeller, Armstrong, Cravens, Laird, and Vitt.

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MAJOR SOLAR FLARES AND LONG-TERM VARIABILITY IN ANTARCTIC ICE CORES

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ABSTRACT

In-Situ data acquisition of high-resolution nitrate concentration in Antarctic snow resulting from ionization in the polar atmosphere reveals (a) very large solar proton events can be resolved, (b) a signal from thermospheric and mesospheric sources is found across Antarctica within the average boundaries of the auroral oval, (c) long-term periods of high or low solar activity, such as the Maunder Minimum are present in the nitrate record.

INTRODUCTION

Our investigations on the Ross Ice Shelf, Antarctica, have shown that accurate and higly detailed information about past solar flare activity can be obtained from Antarctic ice cores by measuring the nitrate concentrations in continuous snow sequences with a simple and very rapid analytical technique, namely UV spectrophotometry. All measurements and data acquisition is performed in the field using ultra-clean, high resolution sampling techniques that have been described in detail /1/.

Solar cosmic rays that are incident upon the earth cause ionization in the polar atmosphere and generate NOx, including nitrate ions (NO3-). Making use of IMP 8 satellite data, ionization of the polar atmosphere has been reported to take place within the stratosphere and even at levels of $\geq$ 20 km for the high energy component of solar protons /2/.

Relatively rapid fallout of such ionization products to the surface of the antarctic ice sheet is of critical importance if the resultant nitrate signal contained in the snow is to be resolved. Within the chemical and dynamical containment vessel of the Antarctic winter vortex, large scale downward motion exists and possibly downward flow taking place particularly rapidly near the vortex boundary /3/. A large role in the removal of nitrate from the atmosphere is played by the presence and build-up of polar stratospheric clouds (PSCs). It has been suggested that PSC particles may grow to about 10 um to permit very rapid downward transport to the tropopause within several days and may be found as nitrate deposited in Antarctic snow /4/. Denitrification of the stratosphere with or without dehydration and nitrate fallout to the Antarctic surface is therefore best described as gravitational fallout or sedimentation /5/; /6/.

Auroral production of NO is shown to be the dominant source at high latitudes. Furthermore, nitric oxide increases within the mesosphere and thermosphere of up to a factor of 10 from periods of low to high solar activity as measured by the polar orbiting satellite Solar Mesospheric Explorer /7/; /8/. Results from the Nimbus 7 spacecraft on global nitric acid distribution show highest concentrations in the polar regions, particularly in the winter polar atmosphere /9/. With observations such as strong downward thermospheric winds measured at a coastal station when located under the equatorward edge of the auroral oval /10/, and possibly non-gaseous, particulate matter (hydrated NO3-ions) near the mesopause at very low mesospheric temperatures /11/, there is good evidence that signals from solar particle produced ionization products can even survive downward transport during the polar summer.

NITRATE SIGNALS OF SOLAR PROTON EVENTS FROM SOLAR CYCLES 22 TO 14

During the 1990-91 field season in Antarctica we drilled 29 meters of firn core by hand and made simultaneous analyses on 1.5 cm snow samples for both nitrate and liquid conductivity using a Beckman Model 160 UV Spectrophotometer and an Orion Model 160 Conductivity Meter. The drill site is about 5 km away from the location of the 1988-89 Antarctic field season in which a 62 year high resolution analytical sequence from the Ross Ice Shelf showed strong anomalies that could be directly associated with specific major solar flare events /1/. In Fig. 1, the equivalent primary peaks are labeled 1972, 1946, and 1928. Methods of dating the snow sequence, experimental techniques and descriptions of the area investigated are provided in earlier works /1/. In addition, to date our most recent snow sequence, we made use of the information from our previous, successive field seasons together with liquid conductivity data.

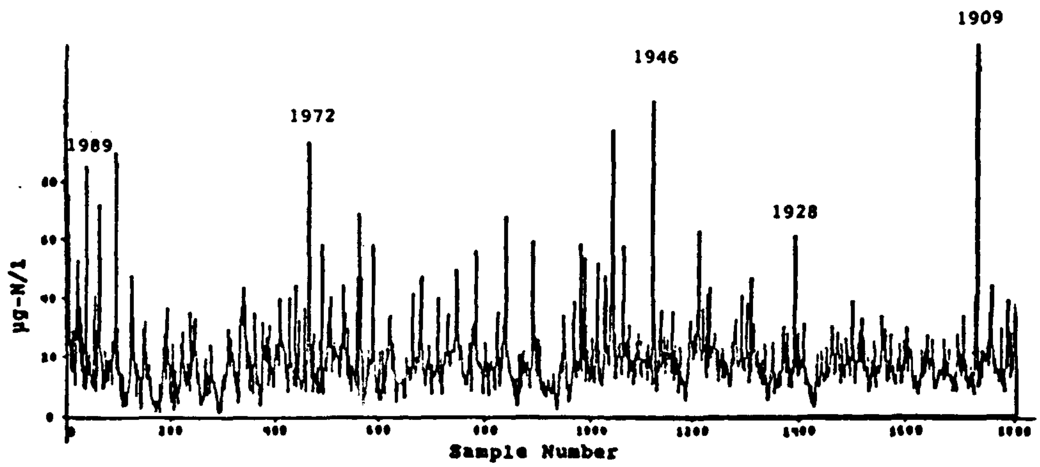

Fig. 1. Firn core from Windless Bight, Antarctica, to a total depth of 29 m. No adjustment for compaction hasbeen made. Anomalous nitrate concentration peaks are indicated by years of their occurence.

It is important to recognize that the primary peaks that have been interpreted as the August 1972 SPE, July 1946 SPE, July 1928 white light flare, are very clearly present in both the 1988-89 ice core sequence and in the 1990-91 ice core as well. Their statistical significance is extremely high. The peak associated with the August 1972 event rises >6 standard deviations above the mean. Similarly, the nitrate peak associated with the July 1946 SPE rises more than ~9 standard deviations above the mean, and for the year 1928, the maximum rises to >4 standard deviations above the mean. This result is completely verified by repeat sampling of these primary peaks. Differences in the secondary peaks between both time series is very apparent and mostly due to depositional effects between the two drill sites.

Another highly significant peak in nitrates (16 standard deviations above the mean) near the maximum depth of our most recent firn core is clearly associated with a visible, pale dust layer approximately 3 cm thick, and has been dated as the year 1909. It is perhaps premature to associate this peak with a specific SPE but stratospheric air may have reached the ground bringing down the nitrates. Following the nitrate fallout two large conductivity peaks may represent sporadic (volcanic) stratospheric sulfate /12/, having its origin in nearby Mt. Erebus. This was confirmed by SEM and simultaneous chemical analysis of dust grains associated with the samples. The few dust grains associated with the NO3 maximum do not show this composition characteristic of Mt. Erebus.

AURORAL ZONE FOOTPRINT IN ANTARCTIC SNOW

In a foot traverse of 5736 km from July 1989 to March 1990 /13/ surface samples were collected on a daily basis between geomagnetic latitudes 50°S West longitude and 77°S East longitude. They were shipped frozen and analyzed in the laboratory for nitrate concentrations. It has been concluded that anomalous nitrate concentrations are either due to nitrate production by ionization from e^- precipitation and solar particle influx into the upper polar atmosphere (a) near the geographic South Pole or maximum ouroral zone /14/ and (b) near stations of the traverse, which may be associated with very penetrating e- precipitation in the magnetic South Atlantic Anomaly /15/.

LONG-TERM SOLAR ACTIVITY IN SNOW SEQUENCES

Firn cores from South Pole (108 m) and Vostok Stations (101 m) on the high polar plateau of Antarctica have been analyzed for trace levels of nitrate /16/. Time series were constructed from the nitrate concentration data and have been subjected to harmonic analysis. Within the constraints of uncertainties in core dating both time series display periodicities that are assignable to solar activity cycles /17/, whereas the better dated upper 200 years of South Pole snow clearly shows the 11 year cyclicity of the sunspot cycle and 22 year periodicity of the Hale cycle.

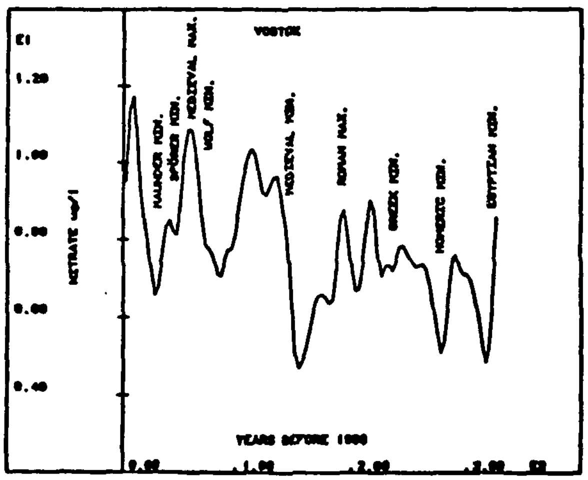

Fig. 2. Cubic spline fit to 20 year averages for nitrate concentration from 1346 data points from the complete Vostok firn core. Historical, solar and climatic data are superimposed.

The two time series are separated by more than 800 km on the Antarctic ice sheet. Both curves show similar trends that must be the result of a process affecting the middle atmosphere over the central part of the Antarctic polar plateau. By applying a cubic spline fit to both time series, broad periods of maxima and minima are displayed which show a close anticorrelation with the carbon-14 record for the equivalent time period. Both nitrate records show the period of known reduced solar activity, the Maunder Minimum from about 1645-1715 with very low nitrate values. Other periods of varying solar activity, particularly the Medieval Maximum is clearly displayed in a general rise in average nitrate concentration. Extending the cubic spline fit to the complete Vostok core, periods lasting several hundred years of lower and higher average nitrate concentrations are seen throughout the ~ 3200 years of record. Approximate historic time periods known from climatic records and carbon-14 variation studies are indicated on the graph in Fig. 2. Similar variations have been found recently in the upper part of the deep ice core currently being drilled on the Greenland ice sheet where nitrate concentrations parallel the timing of the Little Ice Age (Maunder Minimum Period) and the Medieval Warm Period in addition to a relatively strong 12-year periodicity during the Medieval Maximum /18/.

DISCUSSION AND CONCLUSIONS

The primary condition for detection of a specific solar proton event (SPE) seems to be a combination of the winter polar vortex and high particle numbers like that of the August 1972 flare which produced a fluence of 10 E10 protons (cm E2) at the 10 MeV energy level during a period of several days /19/. On the other hand, the ground level event (GLE) of September 1989, the largest GLE in 33 years /20/ may have produced the spike of ~6 standard deviations above the mean during the snow deposited in 1989 (Sample number 38, Fig, 1). The amplitude of this spike is only defined by a single point and would need to be verified later in a sequence analyzed at even higher resolution (2 - 5 mm). Improvement is especially needed in dating snow sequences.

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UNIVERSITY OF KANSAS

DEPARTMENT OF PHYSICS AND ASTRONOMY

COLLOQUIUM

"The Influence of Solar Proton Events on Odd Nitrogen and Ozone in the Middle Atmosphere""

Charles Jackman
NASA Goddard Flight Center

Monday, October 5, 1992
4:00 p.m.
Room 2074 Malott

Coffee and Cookies
3:30 p.m.
Room 1089 Malott

Natural variations in the middle atmosphere can result from the penetration of energetic solar protons. These protons produce odd nitrogen constituents (e.g., N, NO, etc.) through interactions with the background atmosphere at polar geomagnetic latitudes. The odd nitrogen family has a significantly long lifetime in the middle atmosphere (up to several months) and increases in odd nitrogen can lead to decreases in ozone. Solar proton events, which have been linked to significant destruction of ozone, include the August 1972 and the August, September, and October 1989 events. Observations and model simulations of the atmospheric influence of solar proton events will be discussed.

Dr. Charles H. Jackman
Mail Code 916
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

May 8, 1992

Dr. Gisela A. M. Dreschhoff
Codirector
Radiation Physics Lab
Space Technology Center
University of Kansas
Raymond Nichols Hall
2291 Irving Hill Drive - Campus West
Lawrence, KS 66045-2969

Dear Gisela:

Could you please send me a reprint of your paper "Distribution of Nitrate Content in the Surface Snow of the Antarctic Ice Sheet Along the Route of the 1990 International Trans-Antarctica Expedition"? Thanks. The paper certainly presented some provocative measurements and interpretation of the nitrate content along that trans-Antarctica route. I enjoyed discussing the paper with you on the phone last Fall.

We are starting a three-dimensional (3D) modeling experiment of the October 1989 solar proton events. This is a fairly complicated simulation so it will be awhile before we have any results. It will be interesting to see if the NO_x produced by the protons is transported faster downwards in the polar vortex than we have so far simulated in our 2D model experiments.

I hope that your research goes well. Thanks for sending me your previous publications. I would certainly be interested in any more recent manuscripts as well.

Sincerely,

Charley

Charles H. Jackman
Atmospheric Chemistry and
Dynamics Branch